AFCAPS-FR-2011-0003

KSAOs for Military Pilot Selection: A Review of the Literature

Diane L. Damos

Damos Aviation Services, Inc.

Sponsored by

HQ AFPC/DSYX & HQ AF/A1PF

Mr. Kenneth L. Schwartz

Strategic Research and Assessment Branch

February 5, 2011

Air Force Personnel Center

Strategic Research and Assessment

HQ AFPC/DSYX

550 C Street West, Ste 45

Randolph AFB TX 78150-4747

00110 05NOV10
PA Review: Cleared for Public Release
Air Force Personnel Center; Office of Public Affairs
PA: Ms Paige Hughes

NOTICE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
05-02-2011

2. REPORT TYPE
Final

3. DATES COVERED *(From - To)*
August 2009-February 2011

4. TITLE AND SUBTITLE
KSAOs for Military Pilot Selection: A Review of the Literature

5a. CONTRACT NUMBER
W911NF-07-D-0001

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Damos, Diane L.

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Damos Aviation Services, Inc.
36303 N. Old Woods Trail
Gurnee, IL 60031

8. PERFORMING ORGANIZATION REPORT
DAS-2011-01

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Personnel Center
Strategic Research and Assessment Branch
Randolph AFB TX 78150

10. SPONSOR/MONITOR'S ACRONYM(S)
HQ AFPC/DSYX

11. SPONSOR/MONITOR'S REPORT NUMBER(S)
AFCAPS-FR-2011-0003

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release, Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This report reviews nine studies concerned with identifying the knowledge, skills, abilities, and other traits (KSAOs) that are required for success as a military pilot. The report begins with a review of taxonomies used to identify the required KSAOs and notes issues associated with their use. Definitional problems of three attributes commonly associated with success as a pilot—Mechanical Aptitude, Timesharing, and Situational Awareness— are discussed. Next, the studies that identified the required KSAOs are reviewed. Limited conclusions can be drawn about the required KSAOs from (continued on next page).

15. SUBJECT TERMS
Aviator Selection, KSAOs, personality, psychomotor, ability

16. SECURITY CLASSIFICATION OF: Unclassified

a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES
U	U	U	U	39

19a. NAME OF RESPONSIBLE PERSON
Kenneth L. Schwartz

19b. TELEPHONE NUMBER *(include area code)*
210-565-3139

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

14. Abstract (continued)

the studies reviewed. Few investigators examined categories of knowledge as indicators of success. Similarly, the skills required for success were rarely identified because investigators assumed they would be trained. Problems with definitions of abilities and other methodological issues limited the identification of required abilities and restricted cross-study comparisons. Nevertheless, several abilities, particularly Perceptual Speed and Spatial Orientation, were closely associated with success as a military pilot. Identification of other traits required for success was hampered by the lack of strong theories of personality to guide investigators. The report concludes with recommendations for the development of a new taxonomy and for research focused on several attributes that may be critical for success as a military
pilot.

Technical Report
DAS-2011-01

KSAOs for Military Pilot Selection: A Review of the Literature

Diane L. Damos

February 2011

Damos Aviation Services
Meeting pilot hiring needs.

Damos Aviation Services, Inc.
5250 Grand Ave, Suite 14, PMB 124 Gurnee, IL 60031-1877
p 847-855-9582 f 847-855-9584 www.damosaviation.com

ACKNOWLEDGEMENT

This work was supported by the AIR FORCE PERSONNEL CENTER (BRIAN G CHASSE) under the auspices of the U.S. Army Research Office Scientific Services Program administered by Battelle (Delivery Order 0762, Contract No. W911NF-07-D-0001). The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

TABLE OF CONTENTS

ABSTRACT

This report reviews nine studies concerned with identifying the knowledge, skills, abilities, and other traits (KSAOs) that are required for success as a military pilot. The report begins with a review of taxonomies used to identify the required KSAOs and notes issues associated with their use. Definitional problems of three attributes commonly associated with success as a pilot— Mechanical Aptitude, Timesharing, and Situational Awareness—are discussed. Next, the studies that identified the required KSAOs are reviewed. Limited conclusions can be drawn about the required KSAOs from the studies reviewed. Few investigators examined categories of knowledge as indicators of success. Similarly, the skills required for success were rarely identified because investigators assumed they would be trained. Problems with definitions of abilities and other methodological issues limited the identification of required abilities and restricted cross-study comparisons. Nevertheless, several abilities, particularly Perceptual Speed and Spatial Orientation, were closely associated with success as a military pilot. Identification of other traits required for success was hampered by the lack of strong theories of personality to guide investigators. The report concludes with recommendations for the development of a new taxonomy and for research focused on several attributes that may be critical for success as a military pilot.

This page is intentionally left blank

KSAOS FOR MILITARY PILOT SELECTION: A REVIEW OF THE LITERATURE

This report is part of a contract entitled "Historical Scientific Analysis of Aviation Selection." This contract had three goals: 1) describe the development of pilot selection systems from their inception to the present, 2) develop a searchable database of references pertaining to pilot selection, and 3) identify the knowledge(K), skills(S), abilities(A), and other(O) characteristics that are critical to success as a pilot. This report is concerned with the third goal; it reviews studies that have identified the necessary KSAOs for fixed-wing and rotary-wing pilots using ratings by subject matter experts (SMEs) or factor analysis.

This report is narrowly focused and is not concerned with methodological issues pertaining to job analysis or selection instrument development. It also is not concerned with analyses of flying training systems. That is, it does not include reports evaluating military flight training in terms of the knowledge and skills taught versus those needed to fly various military aircraft.

Originally, this report was to include studies that identified the critical KSAOs for both ab initio and experienced civilian pilots, as well as for ab initio military pilots. However, no civilian studies in English were located. Consequently, this reports deals only with the KSAOs for ab initio rotary-wing and fixed-wing military pilots. The KSAOs for unmanned aerial systems are described in a separate report.

Limitations

The studies reviewed in this report allow few conclusions about critical KSAOs because of three recurring methodological problems. The first involves the treatment of knowledge, skills, and "other" characteristics. The second concerns the use of established taxonomies to identify the critical abilities. The third involves the inclusion of attributes in taxonomies that are poorly attested in the literature as abilities. Each of these will be discussed in turn.

Knowledge, Skills, and Other Attributes

Military ab initio flight training assumes that all necessary knowledge and skills are taught during flight training. Consequently, investigators studying critical KSAOs typically are not concerned with knowledge and skills. Indeed, only three studies (Agee, Shore, Alley, Barto, & Halper, 2009; Houston & Bruskiewics, 2006; Youngling, Levine, Mocharnuk, & Weston, 1977) were located that examined the knowledge and skills required to be a successful pilot, and comments about knowledge and skills are limited to these studies.

In the context of pilot selection, "other" attributes usually refer to personality characteristics. Five studies included personality traits in their KSAO lists (Agee et al., 2009; Carretta, Rodgers, & Hansen, 1993; Houston & Bruskiewicz, 2006; McAnulty & Jones, 1984; Youngling et al., 1977). Only Agee et al. provide a source for the personality traits examined in their study. The variety of "personality traits" included in the other four studies suggests that the authors did not obtain their trait list from one, established theory of personality; the traits appear to have been selected from several sources. Houston & Bruskiewicz (2006), however, did take a large number of their traits from the Five Factor Personality Theory. Some traits appear to have been derived from subject matter expert (SME) jargon ("psychological stress resistance," "responsibility for men in combat") and are not attested to in the literature as distinct traits. When appropriate, the lack of attestation is noted.

Taxonomies

All of the studies reviewed were concerned with abilities. Consequently, most of this report is concerned with identifying the abilities that are critical to success as a pilot. No one study can be relied on exclusively to identify those abilities critical to success as a pilot. Instead, the results of many studies must be examined to identify those abilities repeatedly found to be critical. To make meaningful comparisons, all of the studies should use a common (or very similar) framework (taxonomy) of abilities. The scientific literature should attest to each ability included in the taxonomy as a distinct, measurable entity that has been identified through rigorous, scientific testing. Finally, to make meaningful comparisons, the investigators should use the established definitions of the abilities given in the taxonomy. Identifying critical abilities from studies with widely differing definitions of the same abilities is problematic.

Many ability taxonomies have been developed for job analysis and personnel classification (see Knapp, Russell, & Campbell, 1995 for a discussion). These taxonomies have been carefully developed using established scientific methods and provide a carefully constructed description of each ability. One of these taxonomies was developed by Fleishman (see Fleishman & Reilly, 2001 for the most recent version) and is used by most investigators involved in pilot selection. Few investigators, however, use the standard definitions or restrict themselves to the abilities included in the taxonomy.

All five studies using ratings or rankings to identify critical abilities, added abilities to those of Fleishman's taxonomy, or made composites from two or more abilities. The problematic abilities discussed in the next section comprise many of the additions. None of the authors gave any rationale for such additions. However, Miller, Eschenbrenner, Marco, and Dohme (1981) appear to have made the additions because the SMEs participating in the preliminary efforts used terminology that suggested the existence of abilities not included in the taxonomy. Agee et al. (2009) specifically stated that SMEs were allowed to add attributes that they felt were missing.

Composite abilities present a number of interpretation problems. For example, different SMEs may weigh the components differently, which may increase the rating variance and decrease the reliability of the scale. The different weights assigned subjectively by the raters also make comparisons to ratings of individual components problematic. Nevertheless, composite abilities can be useful in certain situations. For example, the study by Driskill, Koonce, Nance, and Weissmuller (2001) was designed to identify specific areas that needed more in-depth research (Weissmuller, personal communication, Jan. 4, 2011). By using composite abilities, the investigators were able to identify promising areas for future research and keep the number of ratings performed by each SME to a reasonable level. A second reason for using composites occurs when SMEs are unable to distinguish between two abilities. Only two of the studies reviewed (Driskill et al., 2001; Houston & Bruskiewicz, 2006) included composite abilities in their attribute list. The composites will not be analyzed further or described because of the above-mentioned interpretation problems.

Problematic Abilities

Three abilities—Mechanical Aptitude, Timesharing, and Situational Awareness—were frequently added to Fleishman's taxonomy. Before the studies are presented, the scientific evidence supporting the existence of Mechanical Aptitude, Timesharing, and Situational Awareness as distinct abilities will be presented. Differing definitions of these abilities will be discussed at the same time because the identification of an ability and its definition are closely related.

MECHANICAL APTITUDE. Several of the studies cited in this report include Mechanical Aptitude in their list of abilities. Carroll (1993) discusses problems associated with Mechanical Aptitude at length. For the purposes of this report, the major problem with Mechanical Aptitude is the lack of a clear empirical distinction between Mechanical Aptitude and various spatial abilities. In data sets containing tests of both spatial ability and Mechanical Aptitude, Carroll (pg. 526) notes that tests of Mechanical Aptitude may correlate highly ("load on") with the Visualization factor, which defines one of three major spatial abilities. Mechanical Aptitude may also load on a factor distinct from that of the spatial ability factors or may load with the spatial ability tests on one factor while also loading on a separate mechanical factor. A second problem noted by Carroll is that Mechanical Aptitude tests may assess two different abilities—one that is associated with mechanical knowledge (familiarity with terminology, the function of various tools, etc.)—and one that concerns judgments of mechanical operations. Most Mechanical Aptitude tests contain a mixture of problems; therefore, separating these two abilities is difficult.

Adding Mechanical Aptitude to Fleishman's taxonomy (Fleishman & Reilly, 2001) may introduce confusion. Fleishman's taxonomy contains two spatial abilities: Visualization and Orientation. Studies using factor analysis to identify the required abilities may find that a test of Mechanical Aptitude does not load on a distinct factor and/or may increase the difficulty of identifying spatial factors. Those studies using SME rankings or ratings to identify critical abilities may encounter a different problem. If Mechanical Aptitude consists of two abilities as Carroll (1993) suggests, then different SMEs may think about Mechanical Aptitude differently. This difference may increase the variance of the ratings/rankings of Mechanical Aptitude and make comparisons with the ratings/rankings of other abilities questionable.

MULTI-TASKING. The existence of some type of a multi-tasking ability has been a matter of discussion for over 100 years (see Damos & Wickens, 1980 for a discussion). Factor analyses show weak and contradictory evidence for such an ability (Carroll, 1993). Nevertheless, many of the taxonomies used in pilot selection include some type of multi-tasking ability.

The definition of this ability differs widely between investigators. Fleishman's definition of Timesharing is "The ability to shift back and forth efficiently between two or more activities or sources of information." The definitions of the other studies that included some type of multitasking attribute are shown in Table 1. The Carretta et al. definition of Divided Attention is the closest to Fleishman's.

The definitions shown in Table 1 differ on three dimensions. The first is successive (Carretta et al.'s Divided Attention, 1993; Miller et al., 1981) versus simultaneous processing (Agee et al., 2009; Carretta et al.'s Timesharing; Driskill et al., 2001; Houston & Bruskiewicz's Divided

Attention, 2006) of input sources. The second dimension includes task prioritization, which may be excluded from the definition (Agee et al., 2009; Carretta et al.'s Divided Attention), included (Driskill et al., 2001; Carretta et al.'s Timesharing), or regarded as a separate ability (Houston & Bruskiewicz, 2006; Miller et al., 1981). The third dimension is task integration, which is included only in the Timesharing definition of Carretta et al. Given the differing definitions of multi-tasking ability, cross-study comparisons must be made with extreme caution.

Table 1
Definitions and Properties of Multi-Tasking Abilities by Study

Study	**Name**	**Definition**	**Simultaneous Versus Successive Processing**	**Prioritization**	**Task Integration**
Agee et al. (2009)	Task Management	"Ability to handle multiple aspects of the mission simultaneously."	Simultaneous	No	No
Miller et al. (1981)	Divided Attention	"The ability to use information obtained by shifting between two or more sensory modalities."	Successive	No	No
Miller et al. (1981)	Establish Priorities	"The ability to determine which of several problems must be solved first."	NA	Yes	No
Driskill et al. (2001)	Multi-tasking	"The ability to effectively prioritize workload and perform simultaneous efforts under demanding situations."	Simultaneous	Yes	No
Houston & Bruskiewicz (2006)	Divided Attention	"To pay attention to multiple tasks occurring at the same time."	?	No	No

Houston & Bruskiewicz (2006)	Cognitive Task Prioritization	"To properly pay attention to tasks in order to achieve subgoals which support the overall mission goal; that is, ensure that the pilot is doing what he or she should be doing at all times."	?	Yes	No
Carretta et al. (1993)	Timesharing	"The ability to observe several sources of information, actions or tasks at the same time, to combine them, allot task priorities, and integrate them into actions that have to be performed."	Simultaneous	Yes	Yes
Carretta et al. (1993)	Divided Attention	"The ability to shift back and forth between two or more sources of information."	Successive	No	No

SITUATIONAL AWARENESS. Arguably, the most problematic construct pertaining to pilot selection is Situational Awareness. Situational Awareness, like multi-tasking abilities, suffers from a lack of an established definition. Perhaps the most common definition is Endsley's (1995), "The perception of the elements in the environment, within a volume of time and space, the comprehension of their meaning and the projection of their status." Three studies reviewed in this report provide other definitions of Situational Awareness. Agee et al. (2009) define Situational Awareness as "the ability to track changing information and events in a dynamic environment and assess impact on the mission." Carretta et al.'s (1993) definition is "the state of constant mental readiness in order to respond to situational changes." Houston & Bruskiewicz (2006) define Situational Awareness as the ability "to accurately perceive self, others, and aircraft in relation to the environment." None of these three definitions is as broad as Endsley's, and all differ significantly from each other.

The scientific status of the Situational Awareness construct is unclear. Carroll (1993) provides no data supporting the existence of Situational Awareness as a distinct ability. However, given that at least three measures of Situational Awareness are needed to identify a specific factor, the lack of factorial evidence for this attribute is not surprising. Carretta, Perry, and Ree (1996) assumed that Situational Awareness is a skill and attempted to predict ratings of Situational Awareness of F-15 pilots by peers and supervisors using flying hours, personality, general cognitive ability, and measures of psychomotor ability. Flying hours demonstrated the highest correlation with ratings, followed by general cognitive ability (visual short-term memory, spatial short-term memory, spatial reasoning, and divided attention). This finding supports the notion that Situational Awareness is a skill, not an ability, that can be improved by practice. Endsley and Bolstad (1994) correlated scores on a measure of Situational Awareness with measures from a battery consisting of biographical data, and spatial, perceptual, and timesharing tests. The study had a small sample (14 to 21 pilots per measure), and only the correlation with single-task tracking performance appeared to be statistically significant. Again, this result points to Situational Awareness as a skill, not an ability.

Comparing Situational Awareness ratings among Agee et al. (2009), Carretta et al. (1993), and Houston & Bruskiewicz (2006) is problematic because of the differences in the definitions. The limited data available appear to indicate that Situational Awareness is a skill that is directly tied to flight time. If Situational Awareness is a skill, its usefulness in an ab initio selection will depend on the cost of training individuals to acceptable levels of proficiency relative to the cost of selecting for high levels of Situational Awareness.

APPROACH—SEARCH STRATEGY

DAS searched four online databases to locate articles for this report: *Ingenta, WorldWideScience.org, PubMed,* and *PsychInfo*. *Ingenta* has over 5 million articles available. No information was readily available on the number of citations included in *WorldWideScience.org*, but any search conducted on the site accesses at least 80 databases. *PubMed* has more than 20 million citations for biomedical literature. The *PsychoInfo* database contains more than 3 million references and includes relevant journals such as *Human Factors, Ergonomics*, and the *International Journal of Aviation Psychology*. DAS searched its own database, which contains over 1900 references pertaining to pilot selection. Additionally, all Air Force Human Resources Laboratory reports published between 1953 and 2010 were searched, as were all of the conference proceedings of the International Military Testing Association. All searches were conducted using the terms “pilot and task analysis,” “pilot and job analysis,” and “pilot job.” The search was restricted to articles published in English.

The search produced only nine relevant reports. Several contractors’ reports could not be obtained from any source, including the Defense Technical Information Center (DTIC). Thus, this report includes only five studies that rated or ranked the KSAOs to identify the most critical attributes, two that used factor analysis, and two that used unique approaches to the problem.

RATINGS STUDIES

Fixed Wing—Ab Initio—General

Driskill et al. (2001) identified the abilities required of United States Air Force (USAF) pilot training candidates. The authors began their study by developing a task list for the T1-A, T-37, T-38, and JPATS aircraft. The authors identified nine categories of abilities to be used in evaluating the tasks. All categories were rated on a scale from 1 (not at all needed to perform the task satisfactorily) to 4 (needed to a great extent). The authors indicate that all nine categories were distilled from Fleishman's work but do not indicate the specific abilities included in the categories. They provide definitions for only four of the categories—Mechanical Aptitude, Selective Attention, Multi-Tasking, and Perceptual Motor Skills. The definitions and problems associated with Mechanical Aptitude and Multi-Tasking have been discussed previously. Driskill et al.'s definition of Selective Attention is similar to that of Fleishman (Fleishman & Reilly, 2001), but their definition of Perceptual Motor Skills corresponds to none of Fleishman's abilities. Three of the remaining categories—Intelligence, Perceptual Skills, and Fine Motor Skills—appear to be composites of several unidentified abilities. One category, Information Recall, cannot be identified with any one or group of Fleishman's abilities. Spatial Orientation also is not defined.

Instructor pilots and student pilots who were currently flying or who were familiar with one of the four aircraft were recruited as raters. Because of the length of the task lists, the respondents were divided into three groups with each group rating the tasks for its aircraft on a different set of three abilities. The ratings of the task lists are not provided in the report. The respondents also rated each of 11 major mission events common to all aircraft in terms of their importance, difficulty to learn, and the extent to which each of the nine KSA categories was needed to perform the major mission event satisfactorily.

The ratings on each of the 11 major mission events are shown in Table 2 below for the categories representing defined, single abilities and for Spatial Orientation. These ratings are averaged across aircraft.

Table 2
Average USAF Pilot Ratings of Need for Four Ability Categories for Performing T1-A, T-37, T-38, and JPATS Mission Events (Driskill et al., 2001)

Mission Event	Ability			
	Spatial Orientation	**Selective Attention**	**Multi-Tasking**	**Mechanical Aptitude**
Mission Planning	1.86	1.73	3.17	2.29
Patterns and Landing	3.48	2.79	2.80	3.46
Contact Airwork	3.27	2.35	2.80	3.10
Instrument Airwork	3.36	2.31	3.17	3.38
Navigation	3.02	2.18	2.91	3.24
Formation	3.59	2.43	2.94	3.63
Penetration and	3.32	2.37	2.97	3.54

Approach				
Emergency Actions	3.24	2.96	3.40	3.72
Communications and Navigation Equipment	2.47	2.38	2.69	2.65
Systems Knowledge	2.09	2.81	3.19	1.83
Post Flight Activity	1.63	1.76	2.42	1.80
AVERAGE ACROSS EVENTS	**2.85**	**2.37**	**2.95**	**2.97**

The only surprising finding in this table concerns Mechanical Aptitude. With the exception of the Systems Knowledge event, Mechanical Aptitude has either the highest or the second highest rating of the four abilities across all of the events. The magnitude of these ratings for events such as patterns and landings and penetration and approach is difficult to understand.

Agee et al. (2009) were concerned with revising the Air Force Officer Qualification Test (AFOQT) to ensure that the KSAOs assessed in the test were the most relevant for ensuring that Air Force officers could attain “fully qualified” status in their Air Force specialty, one of which was pilot. Surveys were distributed to Active Duty, Air Force Reserve Command, and Air National Guard pilots using the internet. The surveys asked the respondents to rate the degree to which a given attribute was characteristic of a fully qualified pilot. The scale ranged from 0 (not required to become qualified) to 5 (fully qualified pilots require a high degree of this ability). Behavioral examples were used to help define the scale values for the raters. Agee et al. received 1092 useable surveys.

The attributes included in the survey initially were derived from Project MIDAS (Dittmar, Weissmuller, Driskill, Hand, & Earles, 1994). Four subsequent focus groups added items, deleted items, changed the definitions, and changed the behavioral anchors. The result was a list of attributes containing 27 “cognitive abilities,” 12 “psychomotor abilities,” and 15 “interpersonal attributes.” Four of the “cognitive abilities” (Technology Literacy, Electro-Mechanical Science, Aviation Knowledge, and Earth/Weather Science) are knowledges and will be discussed separately. Another, Information Processing/Sensor Management, appears to be a combination of computer skills (stream live data…) and Timesharing (drive and listen to GPS instructions). This ability also will not be discussed further. Seven of the “cognitive abilities” appear to be traits or cognitive styles and will be classified as “Other.” Six of the psychomotor abilities are physical abilities (e.g. visual acuity, static strength, etc.), which are not the focus of this report.

The average rating of the 15 cognitive abilities, 6 “other” characteristics, 6 psychomotor abilities, the 4 knowledges, and the 15 interpersonal attributes are shown in Tables 3, 4, 5, 6, and 7, respectively. The attributes are grouped into tables to allow more meaningful comparison with other studies presented later in this report. That is, attributes that Agee et al. (2009) classified as "cognitive abilities" may be placed in the "other" category or in the "knowledge" category to facilitate comparison.

Table 3
Average USAF Pilot Ratings of Cognitive Ability Relevance to Pilot Qualification (Agee et al., 2009)

Ability	**Average Rating**
Situational Awareness	4.88
Spatial Orientation	4.83
Task Management (Multi-Tasking)	4.74
Memorization	4.71
Listening Comprehension	4.69
Mathematical Computation	4.38
Perceptual Vigilance	4.37
Reading Comprehension	4.24
Oral Expression	4.12
Visualization	4.11
Deductive Reasoning	3.90
Inductive Reasoning	3.86
Pattern Recognition	3.62
Mathematical Reasoning	3.56
Written Expression	3.32

Table 4
Average USAF Pilot Ratings of "Other" Characteristic Relevance to Pilot Qualification (Agee et al., 2009)

Characteristic	**Average Rating**
Adaptability	4.78
Prioritization	4.46
Foresight	4.36
Critical Thinking	4.14
Planning	4.00
Perspective	3.91
Resourcefulness	3.78

It should be noted that Prioritization does not refer to a multi-tasking attribute. It is concerned with efficient scheduling.

Table 5
Average USAF Pilot Ratings of Psychomotor Ability Relevance to Pilot Qualification (Agee et al., 2009)

Psychomotor Ability	**Average Rating**
Rate Control	4.45
Choice Reaction Time	4.33
Hand/Eye Coordination	4.31
Finger Dexterity	4.22
Multi-Limb Coordination	3.86
Arm-Hand Steadiness	3.51

Table 6
Average USAF Pilot Ratings of Knowledge Relevance to Pilot Qualification (Agee et al., 2009)

Knowledge	**Average Rating**
Aviation Knowledge	4.75
Electro-Mechanical Science	3.26
Technology Literacy	3.23
Earth/ Weather Science	3.13

Table 7
Average USAF Pilot Ratings for Interpersonal Attribute Relevance to Pilot Qualification (Agee et al., 2009)

Attribute	**Average Rating**
Integrity	4.51
Assuming Responsibility	4.47
Resilience	4.46
Responsiveness	4.44
Self-Discipline	4.35
Decisiveness	4.34
Self-Assessing	4.24
Teaching	4.13
Cooperating	4.01
Work Effectively in Uncomfortable Situations	3.80
Selflessness	3.75
Persuading/ Influencing	3.47
Work Effectively in Isolation Settings	3.43
Mediation	3.27
Empathy	2.95

When evaluating these data, the reader must note that the survey was developed for Air Force officers, not specifically for pilots. Thus, some of the attributes and knowledges are more general than the corresponding constructs in studies examining only pilots. Additionally, SMEs were allowed to change definitions of attributes and add attributes. Thus, Fleishman's definition for a given ability may be very different from the definition included in this survey.

Tables 3 through 7 show very high ratings, with raters indicating that intermediate to high degrees of the cognitive and psychomotor attributes were necessary to become fully qualified.

The only knowledge with a high rating was Aviation Knowledge, which was expected. The “other” attributes generally were rated highly, whereas only the interpersonal attributes that are traditionally associated with pilots (Integrity, Self-Discipline, etc.) were rated highly. The only exception to this pattern was Teaching, which was rated higher than might be anticipated (moderate to intermediate degree needed).

Fixed Wing—Ab Initio—Fighter Track

Carretta et al. (1993) document a NATO working group effort to identify the abilities and traits that are critical to successful performance as a fighter pilot. As part of this effort, 43 fighter pilots from the U.S., Canada, and Norway were asked to rate the importance of each of 20 abilities and 7 traits for the performance of 12 major tasks. The tasks were chosen because they were unique to high-performance fighter aircraft and considered critical for successful performance. Each ability and trait was rated on a 5-point scale. Although no description of the scale is given, the results indicate that higher numbers were associated with greater importance.

Although the authors never specifically cite sources for the abilities and traits, 17 of the 20 abilities match those of Fleishman (Fleishman & Reilly, 2001). Two of the three other abilities are Situational Awareness and Timesharing. Carretta et al.’s (1993) definition of Timesharing and its emphasis on task priorities and the integration of information sources has been noted previously. The authors, however, included a second multi-tasking ability, Divided Attention, which matches Fleishman and Reilly’s (2001) Time Sharing. The one remaining ability, Reasoning, could not be identified and is not discussed further.

The seven traits assessed in this study are Aggressiveness, Risk Taking, Assertiveness, Emotional Stability, Cooperativeness, Leadership, and Achievement Motivation. Emotional Stability is a common name for one of the five major constructs in the Five Factor personality theory (McCrae & Costa, 1997). Achievement motivation is a facet of Conscientiousness, another one of the five major constructs. Thus, although no references are given for the source of the traits, the Five Factor personality theory may have influenced the choice of attributes to be assessed.

SMEs ranked a combined list of the 27 abilities and traits, i.e. the SMEs did not rank the abilities separately from the traits. For the purposes of this paper, the average rank of the traits is presented in a separate table from the abilities. The average rank for each of the 19 identifiable abilities is given in Table 8; the average rank for the traits is in Table 9. The data in these tables were generated only by the U.S. pilots (N=10). The ranks are shown in both tables so that the reader may re-integrate the tables if desired.

Table 8
Average USAF Fighter Pilot Rankings and Ratings of Ability Relevance to Major Tasks (Carretta, 1993; *N* =10)

Ability	Average Rank Order	Average Rating
Situational Awareness	2	4.44
Timesharing	3	4.43
Memorization	4	4.42
Perceptual Speed	6	4.37
Selective Attention	7	4.29
Divided Attention	9	4.19
Spatial Orientation	10	4.14
Response Orientation	11	4.13
Flexibility of Closure	12	4.12
Information Ordering	13	4.04
Psychomotor Coordination	14	3.95
Control Precision	18	3.59
Oral Comprehension	20	3.37
Oral Expression	21	3.35
Visualization	22	3.21
Written Comprehension	23	3.00
Number Facility	24	2.70
Rate Control	26	1.54
Written Expression	27	1.23

Table 9
Average USAF Fighter Pilot Rankings and Ratings of Non-Cognitive Trait Relevance to Major Tasks (Carretta, 1993; *N* = 10)

Trait	Average Rank Order	Average Rating
Achievement Motivation	1	4.51
Aggressiveness	8	4.20
Cooperativeness	15	3.94
Emotional Stability	16	3.92
Risk Taking	17	3.89
Assertiveness	19	3.58
Leadership	25	2.52

Three entries in the tables require comment. As shown in Table 9, Leadership is ranked surprisingly low, 25th out of 27. Table 10 shows that all three abilities associated with psychomotor performance—Psychomotor Coordination, Control Precision, and Rate Control—also were ranked surprisingly low for pilots of fighter aircraft. Finally, the raters clearly saw a difference between Timesharing and Divided Attention, ranking Timesharing as more important (third versus ninth for Divided Attention). This difference could be attributed to the inclusion of task prioritization and integration into the definition of Timesharing or to its emphasis on simultaneous processing versus successive processing in Divided Attention.

Rotary Wing—Ab Initio
Miller et al. (1981) were concerned with developing a mission track selection system that would track select each student aviator for one of the Army's four major aviation missions: aeroscout, utility, cargo, and attack. Miller et al. used a complex process involving a large number of techniques to identify the required KSAOs. Because of the complexity of the process, it will be described here only briefly.

The authors began by identifying the KSAOs that were necessary for the successful completion of each of the four mission types using a combination of interviews, focus groups, and questionnaires. SMEs from all four mission types participated in the interviews and focus groups and completed the questionnaires. Next, Miller et al. (1981) had SMEs rate the tasks required to perform the missions on frequency, difficulty, and criticality. They then used the attributes (abilities and traits) listed on the Army's daily flight evaluation form to identify nine attributes (e.g., Stress Tolerance, Confidence) that were common to all four mission types and asked SMEs to rate the importance of each attribute for the successful completion of each task.

The authors also made a statement pertaining to the importance of each of the nine attributes ("Tolerance to workload-induced stress is the most important factor in mission effectiveness") and constructed a questionnaire of dyad statements. A new group of SMEs selected the statement that was most true. Next, the results of the focus groups and the two questionnaires were combined with the results of informal interviews to produce a list of 20 attributes. SMEs from each of the four mission types were asked to identify and rank the five attributes most important to their mission type.

The different methods of identifying critical KSAOs resulted in sets of non-identical critical attributes. Miller et al. (1981) decided that using an established taxonomy that included most of the ranked attributes was preferable to using only the SME-identified attributes. The authors subsequently compared the attributes ranked as the most important to mission success using these different methods to those of several taxonomies found in the literature and found that Mallamad, Levine, and Fleishman's (1980) taxonomy was the most similar. This taxonomy consists of 29 cognitive and psychomotor abilities and 9 physical abilities. Subsequently, Miller et al. excluded eight physical abilities, three psychomotor abilities, and two cognitive abilities from Mallamad et al.'s list and added Stamina, Establish Priorities, and Stress Tolerance. The definition of Establish Priorities is vague (see Table 1); it could refer to a multi-tasking ability concerned with the performance of concurrent tasks, or it could refer to a task management function concerned with scheduling, e.g. do the flight paperwork before the aircraft inspection. Miller et al. (1981) did not include Fleishman's Time Sharing (Fleishman & Reilly, 2001) in the list but did include Divided Attention (see Table 1 for a definition).

Fifty-two aviators were required to indicate, using seven-point behaviorally-anchored rating scales, the degree to which each of 28 attributes contributed to the successful performance of each mission task. The average ratings were not collapsed across mission types. Miller et al. (1981), however, do present the ten most highly rated attributes by mission type. A total of 16 of the 28 attributes were ranked as critical to one or more of the four mission types. These 16 are shown below in Table 10.

Table 10
Attributes Rated Most Important by U.S. Army Aviators (*N* = 52) (Miller et al., 1981)

Attributes
Perceptual Speed
Speed of Closure
Flexibility of Closure
Problem Sensitivity
Inductive Reasoning
Deductive Reasoning
Spatial Orientation
Visualization
Verbal Expression
Divided Attention
Selective Attention
Multi-Limb Coordination
Control Precision
Rate Control
Reaction Time
Establish Priorities

Perceptual Speed was in the top three most important attributes in all four mission types, as was Problem Sensitivity. Divided Attention was in the top four attributes in three categories and eighth in the fourth. In contrast, Visualization was rated tenth in three mission types and did not appear in the fourth type. Similarly, Multi-Limb Coordination was not included in the top 10 attributes for two mission types and was rated sixth and fourth by two others. Interestingly, both Stamina and Stress Tolerance, which were added to the taxonomy, were never included in the top ten "abilities" for any mission type. Establish Priorities, which was also added, was included in the top ten only once.

Houston & Bruskiewicz (2006) performed a job analysis as part of an effort to develop a new selection battery for Army rotary-wing aviators. The authors began by collecting information on the job and reviewing the literature. They then constructed a preliminary list of all of the tasks performed by an Army aviator and a KSAO list. The KSAO list was developed from a number of sources, which are not identified in the report. The preliminary KSAO list subsequently was reviewed for completeness by a small group of SMEs. Based on SME comments, the authors shortened both the task and the KSAO list and revised the lists to be consistent with Army aviation terminology. The authors then met with four groups of SMEs, who reviewed the task list and each task statement comprising the list. The task list and the task statements were revised again based on the SME comments.

The final task list was distributed to flight instructors at Fort Rucker. Approximately 72% were returned (234 surveys with 212 useable). Each flight instructor was asked to rate the importance of each of the 101 tasks on a 5-point scale (1 to 5). The scale included a "0" that was used if the task was not part of a rotary-wing pilot's job. The instructors also were asked to rate the importance of 12 knowledge categories, 6 skills, 26 abilities, and 48 other characteristics using a

5-point scale. The lowest score (0) corresponded to “not important.” Scores of 1, 2, 3, and 4 corresponded to “somewhat important,” “important,” “very important” and “critical,” respectively.

Houston & Bruskiewicz (2006) provide average ratings for each of the KSAOs. All six of the rated skills pertained to operation of the aircraft or the aircraft systems, such as “operation of sensor/tracking systems and equipment.” Because these skills only can be acquired through helicopter training, they will not be discussed. Most of the 12 knowledge categories also were concerned with information that could only be acquired through military flight training. However, four categories represented information that a motivated ab initio pilot could be expected to know. These are shown below in Table 11.

Table 11
Average Army Flight Instructor Importance Ratings of Knowledge Categories for Rotary-Wing Pilots (*N* = 212) (Houston & Bruskiewicz, 2006)

Category	**Rating**
Flight Rules and Regulations	3.26
Meteorology	2.96
Aeronautical Terminology	2.89
Aviation Principles	2.79

Although the sources for abilities and “other” characteristics for the initial KSAO list are never described, Bruskiewicz, (personal communication, Sept. 29, 2010) indicated that some of the abilities and other characteristics were derived from other projects the company had performed. Seven of the 26 abilities can be identified with those of Fleishman (Fleishman & Reilly, 2001). Another, Spatial Visualization and Orientation, was a composite ability, i.e. the respondents rated the importance of both abilities on one scale, and will not be discussed further. Ratings for the seven abilities are shown in Table 12.

Table 12
Army Flight Instructor Average Importance Ratings of Fleishman’s Abilities for Rotary-Wing Pilots (*N* = 212) (Houston & Bruskiewicz, 2006)

Ability	**Rating**
Multi-Limb Coordination	3.49
Control Precision	3.31
Perceptual Speed	3.29
Selective Attention	3.28
Oral Comprehension	3.25
Simple Reaction Time	3.19
Rate Control	3.14

Ratings for the other 18 abilities are shown in Table 13. Several of these abilities, such as Written Communication, were similar to those of Fleishman (Fleishman & Reilly, 2001) but were defined more narrowly. Others, such as Working Memory and Long-Term Memory, are recognized in newer ability models (See Carroll, 1993 for a discussion), which are not strictly compatible with taxonomies like those of Fleishman. Other constructs like Cognitive Task

Prioritization, Planning, and Vigilance are often used by pilots to describe cockpit behaviors but are not included either in taxonomies or in the newer ability models. Indeed, few data exist supporting Task Prioritization or Vigilance as distinct abilities; Planning and Reading Comprehension are weakly supported as distinct abilities (Carroll, 1993). None of these four abilities is included in Fleishman's taxonomy. As noted in the Multi-Tasking Section, Houston & Bruskiewicz (2006) included a Task Prioritization ability that is distinct from their Divided Attention ability.

Table 13
Army Flight Instructor Average Importance Ratings of Non-Fleishman Abilities for Rotary-Wing Pilots (*N* = 212) (Houston & Bruskiewicz, 2006)

Ability	**Rating**
Situational Awareness	3.76
Divided Attention	3.43
Judgment/ Decision Making/ Problem Solving	3.41
Vigilance	3.35
Choice Reaction Time	3.34
Oral Communication	3.19
Task Prioritization	3.18
Working Memory	3.16
Organization/ Time Management	3.15
Planning	3.13
Learning	3.10
Long-Term Memory	3.08
Analytical Ability	3.03
Time Estimation	2.91
Reading Comprehension	2.85
Mechanical Comprehension	2.75
Mathematical Ability	2.37
Written Communication	2.18

The most salient feature of these two tables is the apparent magnitude of the ratings, which ranged from 3.76 to 2.18. Only five abilities (19.2%) received an average rating below 3.00 (very important). The most highly rated ability was Situational Awareness with an overall rating of 3.76. The problems associated with defining and measuring Situational Awareness were discussed earlier.

The 48 attributes in the "other" category include both personality traits and attitudes. This category shows a different pattern of results from the ability category. The ratings ranged from 1.67 (Dominance) to 3.39 (Teamwork) with 33 attributes (68.8%) receiving a score less than 3.00. Thus, attributes in the "other" category were rated lower than those in the ability category but still seen as important.

Again, no source is given for the personality traits, but they appear to be derived from the Five Factor personality theory (Goldberg, 1993; McCrae & Costa, 1989, 1997). Each of the five personality constructs reflects the common variance among a number of specific traits, which are usually referred to as "facets." For pilot selection, Conscientiousness and Neuroticism are considered to be two of the most important constructs. Conscientiousness is often postulated to reflect six facets: Achievement Striving, Dutifulness, Self-Discipline, Order, Competence, and Deliberation (McCrae & Costa, 1997). Five of these six facets with their ratings were assessed by Houston & Bruskiewicz (2006) and received the following ratings: Achievement Striving (2.92), Self-Discipline (3.21), Order (2.27), Competence (3.13), and Deliberation (2.83). Dutifulness may have been assessed by Dependability (3.19). Thus, these facets were seen as "very important" with the exception of Order, which was considered to be "important."

All of the six facets of Neuroticism also were assessed: Lack of Anxiety (2.79), Lack of Angry Hostility (2.71), Lack of Depression (2.77), Lack of Self-Consciousness (2.80), Lack of Impulsiveness (2.56), and Lack of Vulnerability (3.05). These facets generally were seen as less important than those associated with Conscientiousness and only were rated as "important."

Three other attributes—Stress Tolerance, Risk Tolerance, and Leadership— are often considered to be important characteristics of successful pilots (see Youngling et al., 1977, for a discussion). Stress Tolerance received a high rating, 3.24. In contrast, Risk Tolerance received a lower rating, 2.77. Four leadership attributes were assessed, which were concerned with delegation, goals, performance management, and resolving conflicts. The ratings for these four attributes were 2.32, 2.52, 2.76, and 2.76, respectively. Thus, neither Risk Tolerance nor the four dimensions of leadership were considered "very important" by the average rater.

FACTOR ANALYSIS

Fixed Wing—Ab Initio

Fleishman and Ornstein (1960) identified the abilities underlying success in primary flight training in the USAF. Data were obtained from 63 successful students on 24 non-acrobatic maneuvers taught during primary flight training. Each maneuver was broken down into a number of elements that could be scored as correct or incorrect. The sum of the incorrect elements was recorded as the maneuver score. The authors analyzed the sum of the first four presentations of each maneuver during any given flight.

The authors performed an orthogonal rotation to simple structure and identified six factors. The authors initially attempted to interpret the factors by noting the types of control movements or task requirements that were common to the maneuvers loading on each factor. This approach, however, did not produce any meaningful interpretations. The authors subsequently interpreted the factors in terms of basic abilities, which did provide more meaningful interpretations of the factors. The six factors identified were Fine Control Sensitivity, Spatial Orientation, Multi-Limb Coordination, Response Orientation, and Rate Control. The sixth factor could not be clearly identified with any basic ability and tentatively was labeled Kinesthetic Discrimination.

Rotary Wing—Ab Initio

McAnulty and Jones (1984) examined only the abilities required during the instrument phase of Army helicopter training. The authors selected 27 abilities from Fleishman's work on pilot classification (Myers, Jennings, Schemmer, & Fleishman, 1982) and added five others that they assumed were important for successful performance in this phase of flight training. Two of these additions, Oral Comprehension and Oral Expression, are in Fleishman and Reilly's (2001) list of abilities. However, without definitions, the relation between these two abilities and those of Fleishman and Reilly cannot be determined. Another, Stress Tolerance, may be a personality characteristic rather than an ability. The remaining two, Decision Making and Movement/Position Memory, are not listed in Fleishman and Reilly and have little support from Carroll (1993) as distinct abilities.

The authors developed a list of 16 tasks that students had to learn during the instrument phase of training. Fifteen SMEs rated each task on each of the 32 abilities. Because this report is a short proceedings paper, the authors provide no definitions of the abilities or average ratings by the SMEs. The main analysis of interest is a maximum-likelihood factor analysis with varimax rotation conducted on the rating of the abilities. The resulting factor analysis showed a seven-factor solution: Gross Motor Coordination, Fine Motor Coordination, Closure/Selective Attention, Visual/Perceptual Speed, Information Processing, Originality, and Language. Stress Tolerance and Movement/Position Memory both loaded on only the Gross Motor factor. Decision Making loaded only on the Information Processing factor. The seven factors accounted for about 59% of the variance.

OTHER APPROACHES

Fixed Wing—Ab initio—General

Meyer, Laveson, Weissman, and Eddowes (1974a, 1974b) used a behavioral description approach (see E. A. Fleishman & Quaintance, 1984 for a general description of this approach) to identify the KSAOs required by flight training. Each basic flight maneuver was analyzed according to the stimuli required to cue the pilot to begin the maneuver, the "mental actions" required to perform the maneuver, and the motor responses required to execute the maneuver. Each of these major dimensions was defined further along several subdimensions. For example, the motor response dimension was defined in terms of the number and specific controls (elevators, ailerons, etc.) required to perform the maneuver and the desired final state of the aircraft. The mental actions dimension was subdivided into three subdimensions: complexity, memory accessed (short-term versus long-term), and information processing (recall of facts versus procedures). This method was "validated" by having a group of nine pilots use the taxonomy to describe a set of basic maneuvers. A high level of agreement was found among the pilots. Investigators subsequently used this approach to analyze 34 visual maneuvers for the T-37 and T-38 aircraft.

Using the results of this study to identify the required KSAOs is problematic for two reasons. First, it used a unique taxonomy. Indeed, only two subdimensions—memory accessed and recall of facts versus procedures—approach the current understanding of an ability. Second, SMEs did not actually rank or rate the abilities in terms of their importance to the performance of each maneuver.

Fixed Wing—Ab Initio—Fighter Track

Youngling et al. (1977) were concerned with identifying student pilots who could become good fighter pilots. Unlike the other studies included in this report, Youngling et al. used a combination of interviews, questionnaires, literature review, and analyses of successful pilot selection systems to identify the required KSAOs rather than have the respondents rate or rank the KSAOs. The literature review and the analysis of pilot selection systems were particularly comprehensive and included information from numerous foreign countries. The process of identifying the KSAOs through interviews and questionnaires was conducted in several stages, with the results of early interviews used to develop items for later questionnaires.

The results of all of the sources, including the literature review and analyses of successful pilot selection systems, were combined into a list of 51 "characteristics and critical skills" that were considered necessary for an effective fighter pilot. For the purposes of this report, 17 of the attributes were eliminated from further consideration because they either were medical factors, were listed in tables but never described in the report, or were not KSAOs.

Only one knowledge category—"Equipment Knowledge"—was identified as a critical knowledge. It refers to aeronautical knowledge and technical vocabulary. Two critical skill categories were identified. The first was Flight Skill, which refers to both skill in training and skill in flying fighters. The second skill was Aerial Gunnery.

Interpreting the remaining 34 attributes is problematic because some are components of others.

For example, one of the “skills” was “instrument reading,” which refers to scores on the Instrument Comprehension Test of the AFOQT. One of the “aptitudes” listed was “pilot composite,” which is calculated from scores on the AFOQT including the Instrument Comprehension Test (Carretta & Ree, 1996). The abilities assessed by the tests comprising the pilot composite of the AFOQT are shown in Table 14 as separate entries. The personality attributes and other attributes also are shown in this table.

Table 14
Attributes Considered as Necessary for Success as a Fighter Pilot (Youngling et al., 1977)

Personality and Other Attributes	**Ability Attributes**
Risk Taking	Motor Coordination
Performance Under Stress	Spatial Orientation
Emotional Control	Spatial Perception
Ability to Withstand Psychological Stress	Perceptual Speed
Anxiety Tolerance	Numerical
Aggressiveness	Verbal
Confidence	Mechanical
Consideration for Others	Selective Attention
Personality Style	Decision Time
Courage	Alertness
Responsibility for Men in Combat	
Physical and Combat Leadership	
Teamwork	
Sociability	
Group Loyalty	
Determination/ Desire	
Self-Discipline	
Satisfaction	
Aviation Information	

DISCUSSION

General

Some readers may be concerned with the small number of studies that have sought to identify the KSAOs required for success as a pilot. A larger number of studies would have allowed more comparisons and would have provided a stronger basis for making recommendations. A larger database also could have been examined for trends, such as changes in KSAOs with changes in aircraft technology. The conclusions that can be drawn from the studies are more limited by methodological problems associated with the construction of the taxonomies used to identify the required KSAOs than by the small number of studies. Two of the nine studies reviewed did not use some version of Fleishman's (Fleishman & Reilly, 2001) taxonomy. One of these two, Meyer et al. (1974), used a unique taxonomy that appears never to have been used again for pilot selection. The second, Youngling et al. (1977), did not use any identifiable taxonomy. All five studies that used ratings or rankings (Agee et al., 2009; Carretta et al., 1993; Driskill et al., 2001; Houston & Bruskiewicz, 2006; Miller et al., 1981) modified Fleishman's taxonomy by adding abilities to the list, changing definitions, or creating composite abilities.

None of the studies making additions to the list appear to have identified the missing attributes in a systematic manner, e.g. by consulting other rigorously developed taxonomies or compendiums like Carroll (1993) or identifying the causes of failures in flight training. Instead, most of the additions appear to reflect input from SMEs obtained during focus groups and surveys. SMEs may have used jargon to describe attributes that were not included in Fleishman's taxonomy (Fleishman & Reilly, 2001), and the investigators felt the need to reflect the jargon in the ability lists. In at least one case (Bruskiewicz, personal communication, Sept. 29, 2010), the investigators themselves felt the taxonomy was incomplete and needed additional attributes. As noted earlier, several common additions to the ability list either are not attested as distinct abilities (Situational Awareness) or have weak and conflicting evidence for their existence (Timesharing and Mechanical Aptitude).

Changes to Fleishman's definitions also cause problems in interpreting the results. As described earlier, the most extreme changes concerned Fleishman's Timesharing. Not only was the definition changed, but new multi-tasking abilities that are not attested in the literature also were added to the attribute list. Endsley's (1995) definition of Situational Awareness also was altered significantly. Although Timesharing and Situational Awareness are the most extreme examples of varying definitions, five sets of investigators using the ratings and rankings approach changed many of the ability definitions in less dramatic ways. How these changes affected the ratings and rankings is unknown, and cross-study comparisons must be made very carefully.

With these serious caveats, few general statements can be made about the attributes required for success as a pilot. Historically, several abilities have played prominent roles in pilot selection batteries: Spatial Orientation, Perceptual Speed, Numerical/Quantitative Ability, Timesharing, Mechanical Aptitude, and Multi-Limb Coordination. These will be described below in order. Selective Attention was included in four of the task analysis studies and also will be discussed, as will Situational Awareness. Short sections dealing with knowledge categories and with traits follow the discussion of abilities.

Specific Abilities

SPATIAL ORIENTATION. Spatial Orientation was examined by five studies. Three studies had ratings from "critical" (Youngling et al., 1977) to a ranking of 10 out of 27 (Carretta et al., 1993) to inclusion in the group of most highly rated across mission types (Miller et al., 1981). Both Agee et al. (2009) and Driskill et al., (2001) found that Spatial Orientation received relatively high ratings for flying activities: 4.83 out of 5.0 for Agee et al. and 3+ out of 5 for Driskill et al.
It also was identified in Fleishman and Ornstein's (1960) factor analysis.

PERCEPTUAL SPEED. Perceptual Speed was rated surprisingly highly in all four of the studies in which it was included. Youngling et al. (1977) found that it was a "critical" ability. Carretta et al.'s (1993) SMEs gave it an overall rank of 6 out of 27. It was the most highly rated ability in Miller et al. (1981) and received a "very important" rating in Houston & Bruskiewicz (2006). It also helped define the Visualization/Perceptual Speed factor of McAnulty and Jones (1984).

NUMERICAL/QUANTITATIVE. Numerical/quantitative attributes were included in five studies.
Agee et al. (2009) included two attributes, Mathematical Computation and Mathematical Reasoning, in their study. The definitions of both of these attributes corresponded relatively closely with Fleishman's Number Facility and Mathematical Reasoning (Fleishman & Reilly, 2001). Mathematical Computation was highly rated, 4.38 out of 5.0. Mathematical Reasoning received a lower rating, 3.56 out of 5.0. Numerical skills were considered to be "critical" by the fighter pilots in Youngling et al. (1977) for success as a fighter pilot. However, the fighter pilot raters in Carretta et al. (1993) ranked Number Facility 24th out of 27 abilities. In this study, Number Facility was defined as the degree to which adding, subtracting, multiplying, and dividing can be done quickly and correctly. Houston & Bruskiewicz's (2006) Mathematical Ability, which they defined as "to understand and apply basic (e.g., addition, rounding) and advanced (e.g. algebra) math principles; arithmetic reasoning," was considered "important." Miller et al. (1981) defined Number Facility as "the ability to manipulate numbers in numerical operations, for example, adding, subtracting , multiplying, dividing , integrating , etc. The ability involves both the speed and accuracy of computation." This attribute was not rated in the ten most important attributes for any of the four rotary-wing missions.

The cause of the difference between Youngling et al.'s (1977) rating and Carretta et al.'s (1993) cannot be determined because Youngling et al. did not provide a definition of Numerical Skills. Generally, attributes with definitions similar to Fleishman's Number Facility (the ability to perform basic numerical operations) (Fleishman & Reilly, 2001) received lower ratings than those emphasizing mathematical reasoning. Thus, Miller et al. (1981), Carretta et al. and Agee et al.'s (2009) Mathematical Computation received relatively low ratings. In contrast, Agee et al.'s Mathematical Reasoning and Houston & Bruskiewicz's (2006) Mathematical Ability were more highly rated.

MULTI-TASKING. Ratings and rankings of multi-tasking attributes show a consistent picture of highly rated abilities. Agee et al.'s (2009) raters gave Timesharing a 4.74 out of a maximum of
5.0. In Driskill et al. (2001), Multi-Tasking, which included task prioritization and simultaneous processing, received ratings indicating it was the most important of the four abilities compared for 4 of the 11 major mission events. Carretta et al.'s (1993) Timesharing included simultaneous processing, task prioritization, and task integration. It received a high ranking, 3 out of 27. Their Divided Attention was ranked 9 out of 27. Both Establish Priorities and Divided Attention, which emphasized successive processing, were highly rated by the pilots in Miller et al. (1981). Houston & Bruskiewicz's (2006) Divided Attention, which seems to emphasize simultaneous processing, received a "very important" rating (3.43). Their Task Prioritization also received a "very important" rating (3.18).

The most striking feature of these results is the consistently high ratings obtained by the multi-tasking attributes. The definitions of multi-tasking differed on the nature of the processing (successive versus simultaneous) and the inclusion of two component abilities: Task Prioritization and Task Integration (see Table 1). These differences had no apparent effect on the ratings and, perhaps more importantly, the related attributes (Establish Priorities and Task Prioritization) also received high ratings. This is particularly surprising given the weak attestation in the literature for a Timesharing ability and the complete lack of attestation for other multi-tasking abilities, such as Task Prioritization. The overall impression here is one of a cluster of attributes related to multi-tasking that are perceived as important to both rotary-wing and fixed-wing pilots.

MECHANICAL APTITUDE. Three task analysis studies included Mechanical Aptitude in their attribute list (Driskill et al., 2001; Youngling et al., 1977; Houston & Bruskiewicz, 2006). In Driskill et al. (2001) it was consistently rated as one of the most important abilities. Youngling et al.'s SMEs found that it was "critical" for success as a fighter pilot. Houston and Bruskiewicz's SMEs rated it as "important." Thus, despite academic problems with the identity of a mechanical aptitude, pilot raters consider this an important attribute.

MULTI-LIMB COORDINATION. Multi-Limb Coordination might be assumed to be a highly valued attribute for rotary-wing pilots. However, the task analysis studies for rotary-wing pilots showed mixed results. Multi-Limb Coordination was ranked highly for helicopter pilots in Houston & Bruskiewicz (2006) but not in Miller et al. (1981). Although a similar assumption could be made for its importance in flying fighter aircraft, Multi-Limb Coordination was ranked 14th out of 27 attributes for fighter pilots by Carretta et al.'s (1993) SMEs. In Agee et al. (2009), it received a rating of only 3.86 out of a maximum of 5.0. It loaded only on the gross psychomotor factor in McAnulty and Jones (1984).

The differences between Houston & Bruskiewicz (2006) and Miller et al. (1981) may be attributable to differences in the importance of Multi-Limb Coordination among the four Army mission types: scout, utility, cargo, and attack. Multi-Limb Coordination was rated highly (in the top ten most important attributes) only for the attack and utility missions in Miller et al. The same pattern was true for Houston and Bruskiewicz although the overall (average across mission types) rating was 3.49 out of 4.0 ("very important"). Thus, the apparent differences between these two studies may be attributed to differences in the way the data were averaged. When the data are examined by mission type, the results from the two studies basically agree: Multi-Limb coordination is important for attack and utility missions. No explanation can be offered for the average ranking given by Carretta et al.'s (1993) fighter pilot raters or for the relatively low rating in Agee et al. (2009).

SELECTIVE ATTENTION. Selective Attention was examined in four of the rating studies. Miller et al. (1981) found that it was ranked in the top 10 critical attributes for all four Army mission types. Its ratings were relatively low in Driskill et al. (2001) (2+ out of 5), indicating that the respondents felt that this ability was not greatly needed to perform major mission events successfully. It was considered to be "critical" by Youngling et al. (1977). Carretta et al. (1993) found that its average rank was 7 out of 27, indicating that their respondents, who were all fighter pilots, considered it important. Thus, three of the four studies consider Selective Attention to be an important attribute for success as a pilot.

SITUATIONAL AWARENESS. Agee et al. (2009), Houston & Bruskiewicz (2006), and Carretta et al. (1993) included Situational Awareness in their list of attributes. Situational Awareness received the second highest average rank in Carretta et al. and the highest average rating in Agee et al. and Houston and Bruskiewicz. However, the three definitions differ significantly from each other (see the Situational Awareness Section). That of Agee et al. is reasonably close to Endsley's (1995) definition and emphasizes change in a dynamic environment. That of Carretta et al. implies something like alertness or vigilance. Houston & Bruskiewicz's (2006) definition may imply a three-dimensional image. In any case, these definitions differ substantially from each other and may not assess the same attribute. Because of the substantial differences in the definitions, no conclusions can be drawn from these studies about the importance of Situational Awareness for success as a military pilot.

Knowledge

Only three of the studies were concerned with identifying the types of knowledge that might discriminate between a successful and an unsuccessful pilot at the ab initio level. Raters in Agee et al. (2009) gave aviation knowledge an average rating of 4.75 out of 5.0. Youngling et al. (1977) identified aeronautical knowledge and technical vocabulary as critical. Houston & Bruskiewicz (2006) identified four categories of knowledge that potentially could be used to select ab initio pilots: principles of aviation, meteorology, aeronautical terminology, and flight rules and regulations. These results are consistent with traditional military selection processes, which typically assess categories of aviation knowledge.

Traits

Like knowledge, little can be said about the personality traits needed for success as a pilot because only four studies—Agee et al. (2009), Carretta et al. (1993), Houston & Bruskiewicz (2006), and Youngling et al. (1977)—examined them. Any discussion of important traits is limited further because the four studies used different approaches to generating their "other" characteristics list. Houston and Bruskiewicz drew many of their traits from the Five Factor personality theory; Carretta et al. may have made limited use of this theory. Agee et al. generated an initial list apparently from a previous Air Force study. The final list, however, was the result of additions, deletions, and definitional changes made by SMEs. The result was that the lists of "other" and "interpersonal" attributes share no attributes with those of the other three studies. Youngling et al. also generated their list from SME input, as well as from a literature review and an examination of foreign selection systems. Predictably, few attributes are shared with Carretta et al. and Houston and Bruskiewicz.

The two most important dimensions of the Five Factor Theory for pilot selection appear to be Conscientiousness and Neuroticism (Anesgart & Callister, 1999). The facets of Conscientiousness received "very important" ratings in Houston & Bruskiewicz (2006). One trait in Carretta et al. (1993), Achievement Motivation, is a facet of Conscientiousness. This facet was ranked as 1 out of 27 in terms of importance for success as a fighter pilot. Similarly, the facets related to Neuroticism (Emotional Stability) received ratings of "important" in Houston and Bruskiewicz. In Carretta et al., Emotional Stability ranked 16 out of 17. Thus, the results based on the Five Factor Theory seem consistent across these two studies.

Interestingly, Leadership, Stress Resistance, and Risk Taking were considered to be "critical" by Youngling et al.'s (1977) raters. Carretta et al.'s (1993) raters ranked Leadership 25 out of 27 and Risk Taking, 17 out of 27. The four leadership attributes and Risk Tolerance in Houston & Bruskiewicz (2006) were rated as "important," whereas Stress Tolerance was rated as "very important."

These results show that traits related to Conscientiousness are considered to be very important for success as a pilot. Traits related to Emotional Stability are considered less important. Risk Tolerance, Stress Tolerance, and Leadership show mixed results but are seen as less important than traits pertaining to Conscientiousness.

SUMMARY AND RECOMMENDATIONS

Few general conclusions can be drawn from these studies about the importance of specific attributes because of the definitional problems and the differing uses of taxonomies for identifying KSAOs. With that caveat, the two most important abilities are Perceptual Speed and Spatial Orientation. Numerical/Quantitative abilities, Multi-Tasking attributes, Multi-Limb Coordination, and Selective Attention received mixed support. Both Mechanical Aptitude and Situational Awareness also were rated highly. However, no general statement about the importance of these attributes can be made because of differences in their definitions.

Three recommendations for future research can be made. The first concerns the taxonomy used to identify the required KSAOs. The numerous modifications of Fleishman's taxonomy indicate that the taxonomy is not sufficient in its current instantiation. The USAF should consider the construction of an expanded taxonomy that would include personality traits and other characteristics. Currently, the O*NET Content Model provides an expanded taxonomy of non-cognitive characteristics relevant to civilian occupations (including piloting) that may provide a useful organizing point for future research (National Center for O*NET Development, n.d.). For instance, subject matter experts in one or more of the studies reviewed in this report identified the following five O*NET Work Styles, or a closely related construct, as relevant to military pilots: Achievement/ Effort (Carretta, 1993), Adaptability/ Flexibility (Agee et al., 2009), Cooperation (Agee et al., 2009; Carretta, 1993), Integrity (Agee et al., 2009), and Self Control (Agee et al., 2009).

Second, more research on Mechanical Aptitude is needed. The relation between Mechanical Aptitude and the spatial abilities needs to be clarified. The nature of Mechanical Aptitude also needs to be studied to determine if this construct is composed of two abilities as Carroll (1993) suggests or only one.

Third, research on Situational Awareness should focus on addressing problems pertinent to pilot selection. One of these problems concerns the nature of the construct. O'Brien and O'Hare (2007) summarize research on Situational Awareness and suggest that it has a hierarchical structure with basic perceptual abilities at the lowest level and higher cognitive abilities at the top. The nature of Situational Awareness (hierarchical arrangement versus single specific) has implications for selecting individuals with high levels of the construct. If Situational Awareness reflects multiple abilities arranged in a hierarchical manner, the underlying abilities need to be identified and their relation determined. Another problem concerns the various measures of Situational Awareness. Questions pertaining to exactly what is being measured need to be addressed. Additionally, the measures need to be examined in terms of selection. That is, the reliability and validity of the measures must be established and the presence of group differences determined.

On the whole, the results of this review provide limited insight into the KSAOs that are required for successful performance as a pilot. The lack of progress in this area can be attributed in part to problems with taxonomies and to a lack of understanding of the nature of some of the most promising attributes. A concerted effort should be made to correct these deficiencies in a timely manner.

REFERENCES

Agee, R. C., Shore, W. C., Alley, W. E., Barto, E., & Halper, M. (2009). Air Force Officer Selection Technical Requirements Survey. Volume 1; Analysis of Quantitative Results. San Antonio, TX: Chenega Corporation.

Anesgart, M. N., & Callister, J. D. (1999). Predicting training success with the NEO: The use of logistic regression to determine the odds of completing a pilot's screening program *Proceedings of the Tenth International Symposium on Aviation Psychology*. Columbus, OH: The Ohio State University.

Carretta, T. R., Perry, D. C., Jr., & Ree, M. J. (1996). Prediction of situational awarness in F-15 pilots. *International Journal of Aviation Psychology, 6*, 21-42.

Carretta, T. R., & Ree, M. J. (1996). Factor structure of the Air Force Officer Qualifying Test: Analysis and Comparison. *Military Psychology, 8*(1), 29-42.

Carretta, T. R., Rodgers, M. N., & Hansen, I. (1993). *The Identification of Ability Requirements and Selection Instruments for Fighter Pilot Training*. (AL/HR-TP-1993-0016). Brooks AFB, TX: Armstrong Laboratory.

Carroll, J. B. (1993). *Human cognitive abilities A survey of factor-analytic studies*. New York, NY: Cambridge University Press.

Damos, D. L., & Wickens, C. D. (1980). The identification and transfer of timesharing skills. *Acta Psychologica, 46*, 15-39.

Dittmar, M. J., Weissmuller, J. J., Driskill, W. E., Hand, D. K., & Earles, J. A. (1994). *Methodology for Identifying Abilities for Job Specialties (MIDAS)*. (AL/HR-TP-1994-0008). Brooks AFB, TX.

Driskill, W. E., Koonce, J. M., Nance, P., & Weissmuller, J. J. (2001). *Skills, Knowledge, and Abilities Underlying Success in USAF Pilot Trainining*. (Technical Report No. AFRLHE-AZ-TR-2000-0005). Mesa, AZ: Air Force Research Laboratory.

Endsley, M. (1995). Toward a theory of situation awareness in dynamic systems. *Human Factors, 37*, 32-64.

Endsley, M. R., & Bolstad, C. A. (1994). Individual differences in pilot situational awareness. *International Journal of Aviation Pychology, 4*, 241-264.

Fleishman, E. A., & Ornstein, G. N. (1960). An analysis of pilot flying performance in terms of component abilities. *Journal of Applied Psychology, 44*, 146-155.

Fleishman, E. A., & Quaintance, M. (1984). *Taxonomies of Human Performance*. Potomac, MD: Management Research Institute, Inc.

Fleishman, E. A., & Reilly, M. E. (2001). *Handbook of Human Abilities*. Potomac, MD: Management Research Institute, Inc.

Goldberg, L. R. (1993). The structure of phenotypic personality traits. *American Psychologist, 48*(1), 26-34.

Houston, J. S., & Bruskiewics, K. T. (2006). *Development and preliminary validation of a selection instrument for U.S. Army flight training (SIFT): Volume 2*. (PDRI 523). Minneapolis, MN: Personnel Decisions Research Institutes, Inc.

Houston, J. S., & Bruskiewicz, K. T. (2006). *Development and prelimnary validation of a selection instrument for U.S. Army flight traiing (SIFT): Volume 1*. (PDRI 523). Minneapolis, MN: Personnel Decisions Research Institutes, Inc.

Knapp, D. J., Russell, T. L., & Campbell, J. P. (1995). *Building a joint-service classificationresearch roadmap: Job analysis methodologies*. (AL/HR-TP-1994-0027). Brooks AFB, TX.

Mallamad, S. M., Levine, J. M., & Fleishman, E. A. (1980). Identifying ability requirements by decision flow diagrams. *Human Factors, 22*(1), 57-68.

McAnulty, D. M., & Jones, D. H. (1984). An evaluation of aviator training ability requirements scale ratings *Proceedings of the Human Factors Society 28th Annual Meeting* (Vol. 28 (4), pp. 356-360).

McCrae, R. R., & Costa, P. T., Jr. (1989). More reasons to adopt the five-factor model. *American Psychologist, 44*(2), 451-452.

McCrae, R. R., & Costa, P. T., Jr. (1997). Personality trait structure as a human universal. *American Psychologist, 57*(5), 509-516.

Meyer, R. P., Laveson, J. I., Weissman, N. S., & Eddowes, E. E. (1974a). *Behavioral taxonomy of undergraduate pilot training tasks and skills: Taxonomy refinement, validation and operations*. (AFHRL-TR-74-33(III)). Brooks Air Force Base, TX: Air Force Human Resources Laboratory.

Meyer, R. P., Laveson, J. I., Weissman, N. S., & Eddowes, E. E. (1974b). *Behavioral taxonomy of undergraduated pilot training tasks and skills: Surface task analysis, taxonomy structure, classification rules and validation plan*. (AFHRL-TR-74-33(III)). Brooks Air Force Base, TX: Air Force Human Resources Laboratory.

Miller, J. T., Eschenbrenner, A. J., Marco, R. A., & Dohme, J. A. (1981). *Mission track selection process for the Army Initial Entry Rotary Wing flight training program. Volume I*. St Louis, MO: McDonnell Douglas Astronautics Co.

Myers, D. C., Jennings, M. C., Schemmer, M., & Fleishman, E. A. (1982). *Validation of cognitive and perceptual-motor tests for assigning pilots to different missions: Development of computer-interactive tests*. (ARRO-3075-TR). Bethesda, MD: Advanced Research Resources Organization.

National Center for O*NET Development for USDOL (n. d.). The O*NET content model: Detailed outline with descriptions. Retrieved from http://www.onetcenter.org/dl_files/ContentModel_DetailedDesc.pdf

O'Brien, K. S., & O'Hare, D. (2007). Situational awareness ability and cognitive skills training in a complex real-world task. *Ergonomics*, *50*(7), 1064-1091.

Youngling, E. W., Levine, S. H., Mocharnuk, J. B., & Weston, L. M. (1977). *Feasibility study to predict combat effectiveness for selected military roles: fighter pilot effectiveness*. (MDC E1634). East St Louis, MO: McDonnell Douglas Astronautics Co.